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An artificial neural network model for analysis and design of microstrip lines

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Abstract : Artificial neural networks have been designed in the frequency range of 0.5 GHz. to 30 GHz to analyze and synthesize the impedance and dispersion characteristics of microstrip transmission lines. Results obtained by this method have been compared with the results obtained using the software MWI and experiment. These results show a good parity for specified range of parameters.

Keywords : Microstrip transmission lines, artificial neural networks, backpropagation algorithm.

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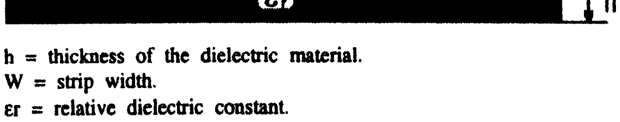
There are various methods of microstrip analysis, which may be divided into three groups : Quasi-static approach, Dispersion model and Full wave analysis [1]. Due to the increasing use of microstrip lines in higher frequency regimes, numerous papers on the study of their characteristics have been published. Excellent summaries and reviews of the methods employed in the studies are given by different authors [2–6]. To avoid the mathematical complexity of previous works and to generalize the studies over a vast range of parameters, Artificial Neural Network (ANN) model is introduced. A four-layer ANN, with three hidden layers, is trained with available data. After training, the absolute average error of ANN is observed to be less than 2% with respect to MWI [7]. In our neuron model, multi-layer feedforward network trained by backpropagation algorithm is used as they offer immense scope for exact representation of a broad class of input/output maps [8,9]. The model is used to obtain effective dielectric constant (ε_{reff}) and characteristic impedance (Z_0) of a microstrip line for a given set of parameters like dielectric thickness (h), strip width (w), relative dielectric constant (ε_r) and frequency of operation (f).

A similar type of ANN model is used again to determine the microstrip transmission line width for required characteristic impedance. Here also, the results obtained from ANN have an absolute average error less than 2% with respect to MWI. A microstrip transmission line is fabricated for a characteristic impedance of 50 Ω which has been designed by the ANN technique. Its experimental measurement of characteristic impedance shows an excellent agreement with the designed value. So it is proposed that the ANN model may be used to analyze and synthesize microstrip characteristics with a reasonably small error.

A typical microstrip line is shown in Figure 1. For analysis it is assumed that the effective relative permittivity



h = thickness of the dielectric material.
W = strip width.
εr = relative dielectric constant.

Figure 1. A typical microstrip line.

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(ε_{reff}) and characteristic impedance (Z_0) of microstrip transmission line are continuous functions of four variables, within specified range, *viz.* the thickness of the dielectric material (h), width of the strip (w), relative effective dielectric constant of the dielectric material (ε_r) and frequency of operation (f). The selected range of the four variable are; h = 0.5 mm to 4.5 mm, w = 0.2 mm to 9 mm, f = 0.5 GHz. to 30 GHz and ε_r = 2 to 10. In the feedforward network used, four units are required in the input layer. There are thirteen units in the first hidden layer (counting from the input side), nine units in the second hidden layer, five units in the third hidden layer and finally two units in the output layer as shown in Figure 2. To analyze, the values of the four inputs are considered proportional to the dielectric thickness, width of the strip, relative dielectric constant and frequency of operation. The values of two outputs are proportional to the effective relative dielectric constant and characteristic impedance. The popular sigmoidal function, given by $f(x) = [1/\{1 + \exp(-\lambda x)\} - \alpha]$, where $f(x)$ is the output of the unit, x is the total input to the unit, λ is the activation gain and α is the threshold, is considered for representation of the input/output relationship for each unit. All thresholds are assumed to be zero and all activation gains are assumed unity. As it is assumed that each neuron is characterized by a sigmoid function [8], to normalize the values of all variables between 0 and 1, dielectric thickness is divided by five and strip width, relative dielectric constant and effective relative dielectric constant are divided by ten, frequency is divided by thirty and characteristic impedance is divided by two hundred.

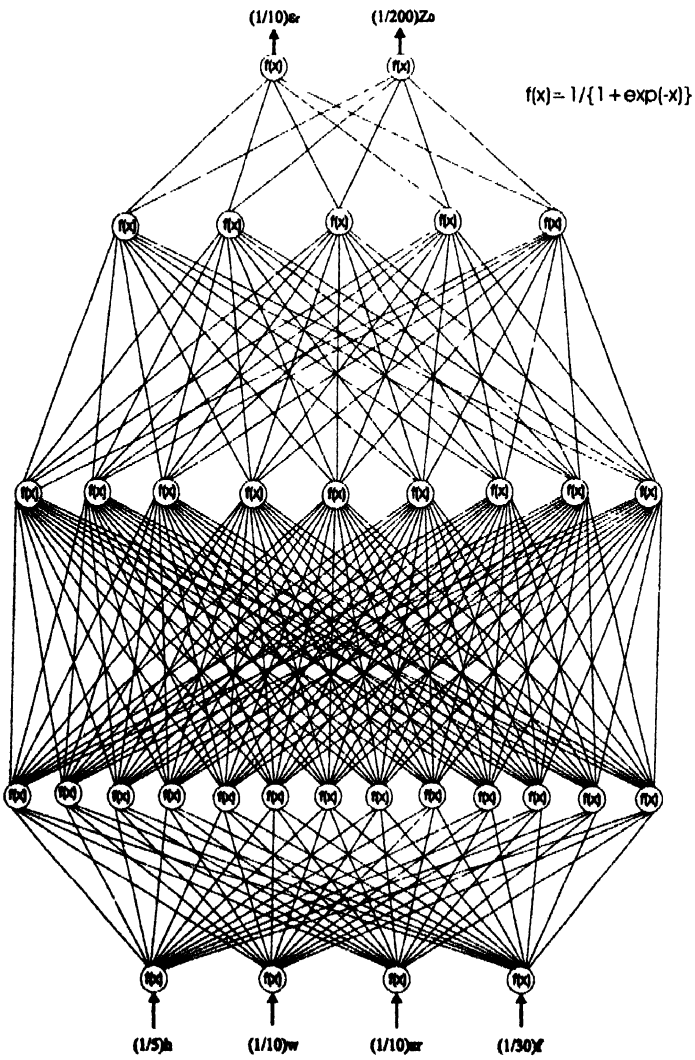

Figure 2. Four input two output three hidden-layered feedforward network for back-propagation.

To minimize error for the vast range of input parameters, three hidden layers are used. The network is trained with 950 data sets for w/h = 0.05 to 5 with the help of Backpropagation Algorithm. After nearly 700,000 iterations with a variable learning rate of 0.00013 to 0.01, the final network values yielded an average of absolute error of less than 2% with respect to MWI.

Almost the same network is used for synthesis as shown in Figure 3. There is one unit in the output layer. In this case the value of four inputs are proportional to the dielectric thickness, characteristic impedance of the strip, relative dielectric constant and frequency of operation and the output is proportional to the value of width of the strip. For normalization, each variable is divided by the same factor as before except the strip width, which is divided by fifteen. This network is also trained with 950 data sets for w/h = 0.05 to 5 with the help of Back-propagation Algorithm. Here, the range of the strip width is taken to lie within 0.2 mm to 13 mm After nearly 500,000 iterations with a variable learning rate of 0.00013 to 0.03, the final network values yielded an average of absolute error of less than 2% with respect to MWI.

The trained ANN for analysis is used to compute the variation of characteristic impedance and effective relative dielectric constant with frequency for different combination of dielectric thickness, strip width and relative permittivity of the dielectric material. The results are plotted along with the corresponding results obtained using MWI for comparison in Figures 4.1 to 5.4.

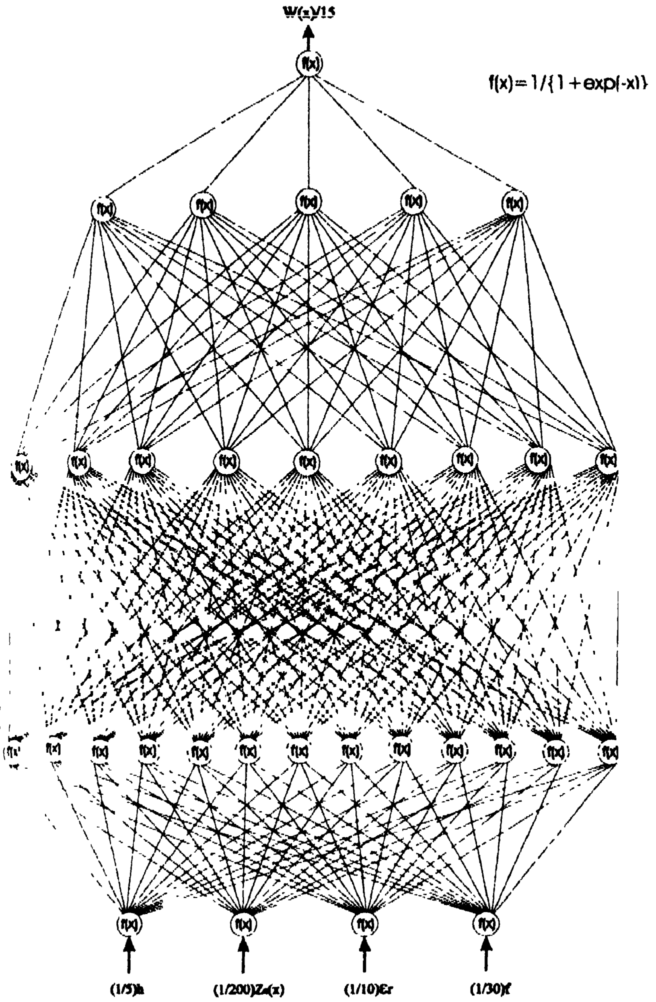

Figure 3. Four input one output three hidden-layered feedforward network for back-propagation.

Further, the trained ANN for synthesis is used to compute the variation of strip width with frequency for different combination of dielectric thickness, characteristic impedance and relative permittivity of the dielectric material. The results are plotted along with the results obtained by MWI in Figures 6.1 to 6.4. Further with the help of our studies, a 50 Ω line with dielectric thickness 1.524 mm, relative dielectric constant 2.2 and an operating frequency of 5 GHz was designed and fabricated. Measurements for reflection coefficient with the line terminated by a 50 Ω matched load showed perfect matching at 5 GHz, whereas at 5.015 GHz the SWR was found to be 1.065

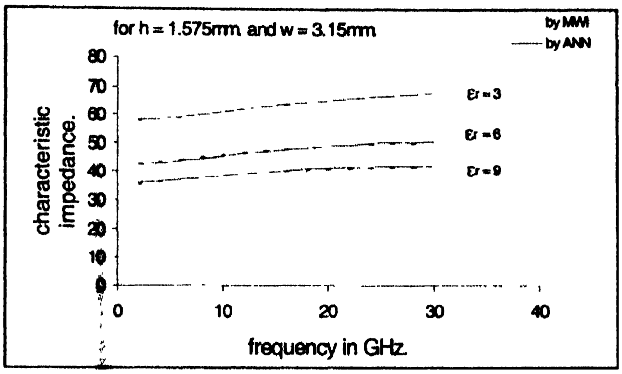

Figure 4.1

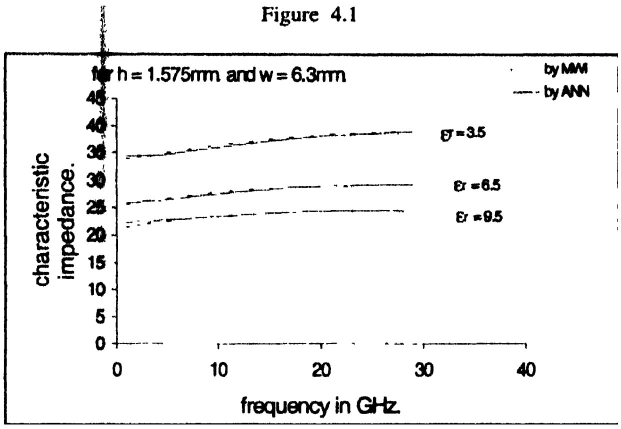

Figure 4.2

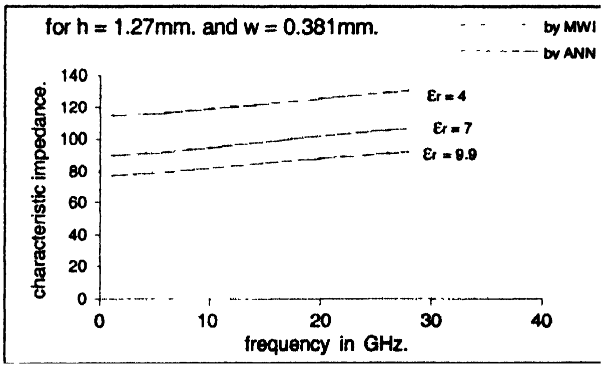

Figure 4.3

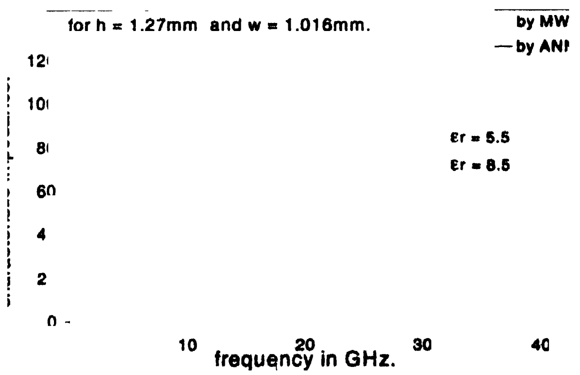

Figure 4.4

Figure 4.1–4.4. Plot of characteristic impedance in ohm *vs* frequency in GHz for different *w/h* ratio and different *ε*.

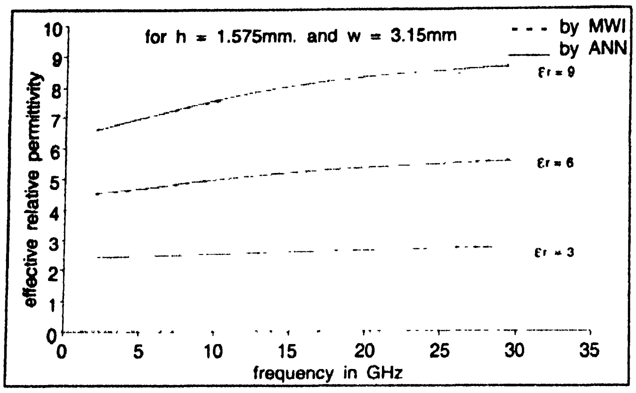

Figure 5.1

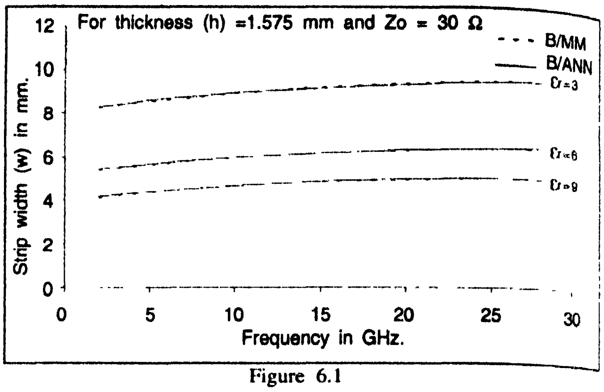

Figure 6.1

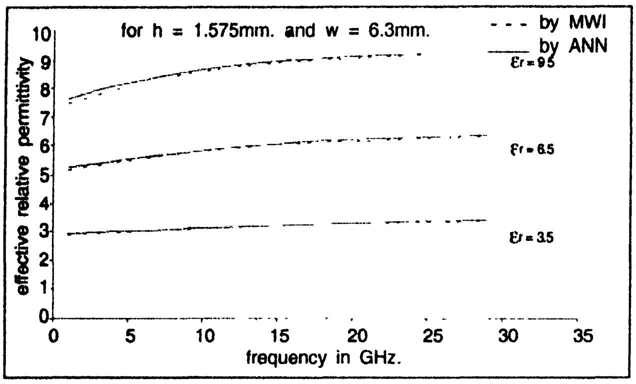

Figure 5.2

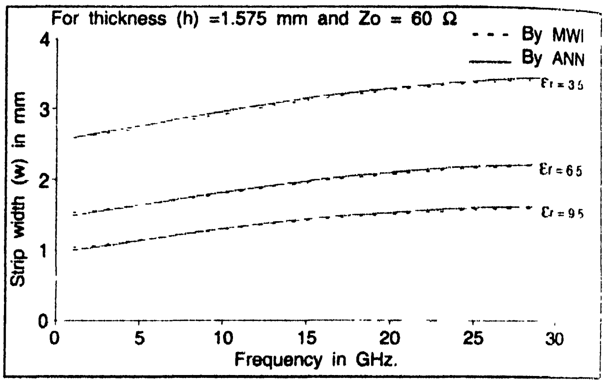

Figure 6.2

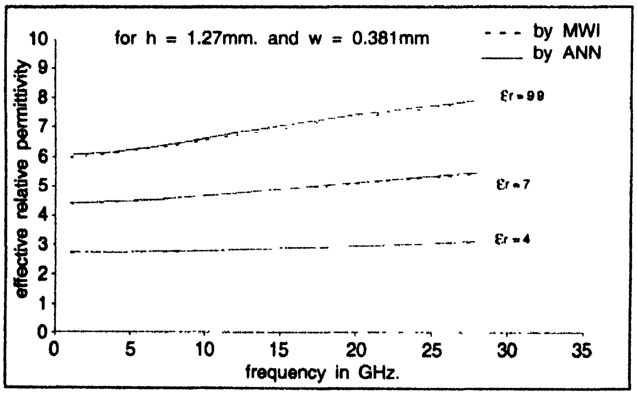

Figure 5.3

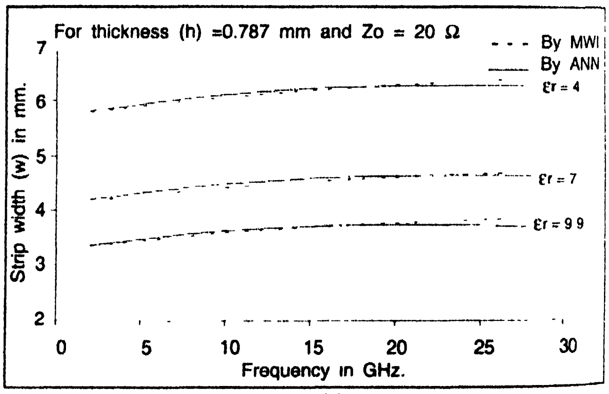

Figure 6.3

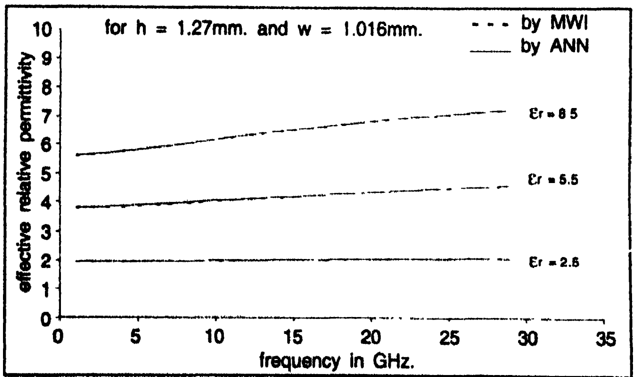

Figure 5.4

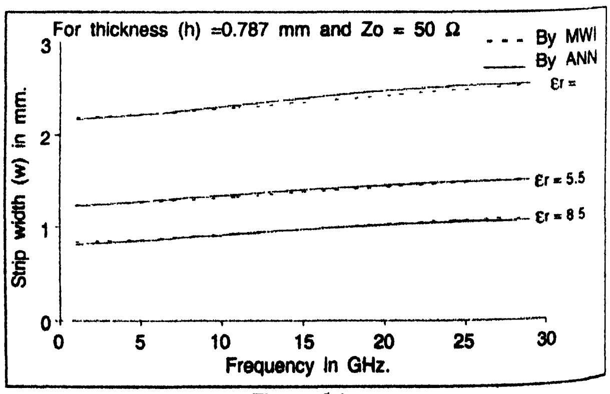

Figure 6.4

Figure 5.1–5.4. Plot of effective relative permittivity *vs* frequency in GHz for different *w/h* ratio and different ε_r.

Figure 6.1–6.4. Plot of strip width *vs* frequency in GHz for different value of Z_0 and different ε_r.

It is seen from the plots that the results obtained using ANN are in excellent agreement with results obtained using MWI. It is shown that once ANNs are trained, then for different value of input variables, within the specified range, outputs may be obtained for both analysis and design purpose without further mathematical calculation with a very small error.

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